Sea ice variability in the Ross Sea forced by tides: Satellite observations and modeling

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Introduction

The Ross Sea is an area with strong diurnal tides (Fig. 1) and variable sea ice concentration (C_{ice}). We developed a new method using AMSR-E swath data to extract tidal coefficients from C_{ice}. Our focus is on a 25x25km box in the Northwest corner (Fig 2.), from which we expand the analysis to the entire Ross Sea and compare satellite results to a regional ocean model. The model allows us to further investigate tidal effects on ice and heat fluxes by comparing runs with and without tidal forcing.

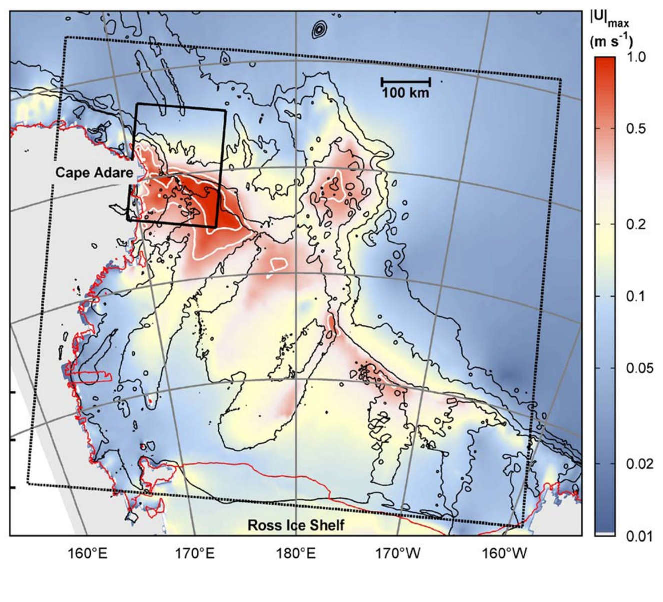

Figure 1. *Maximum tidal velocity (m/s) for the Ross Sea, from Padman et al, 2009.*

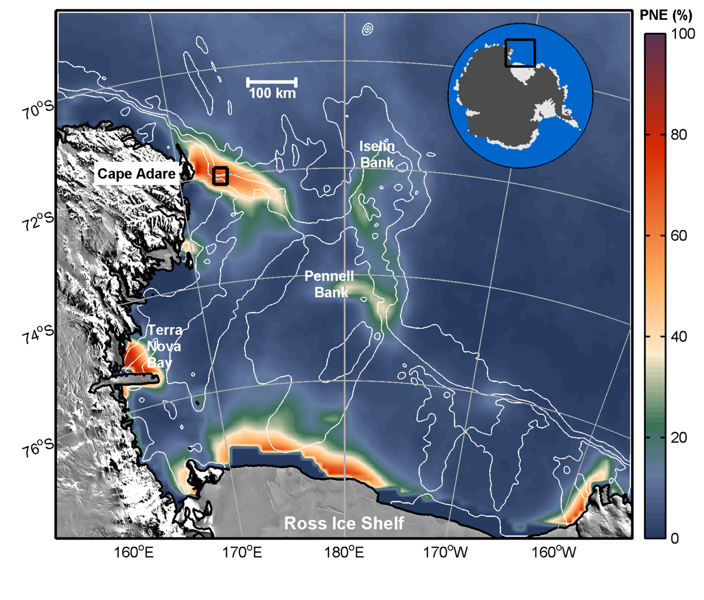

Figure 2*. *Probability of non-exceedance of Cice for a threshold of .95 over Apr-Nov 2002-2009 from AMSR-E daily averages.*

Satellite Data

We extracted tidal amplitudes in C_{ice} from AMSR-E single swath data. Due to the nature of the satellite track, the data is very irregularly sampled (Fig. 3). By interpolating the data to 2-hr intervals using cubic splines and filtering with a high-pass Butterworth filter, we were able to extract tidal coefficient amplitudes using T_Tide, a Matlab toolbox by Rich Pawlowicz.

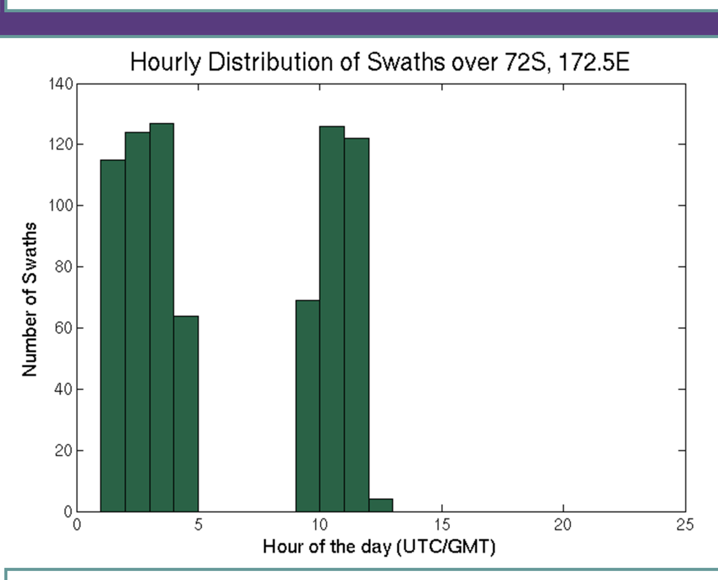

Figure 3*. *Frequency of swath passes over NW corner in one year.*

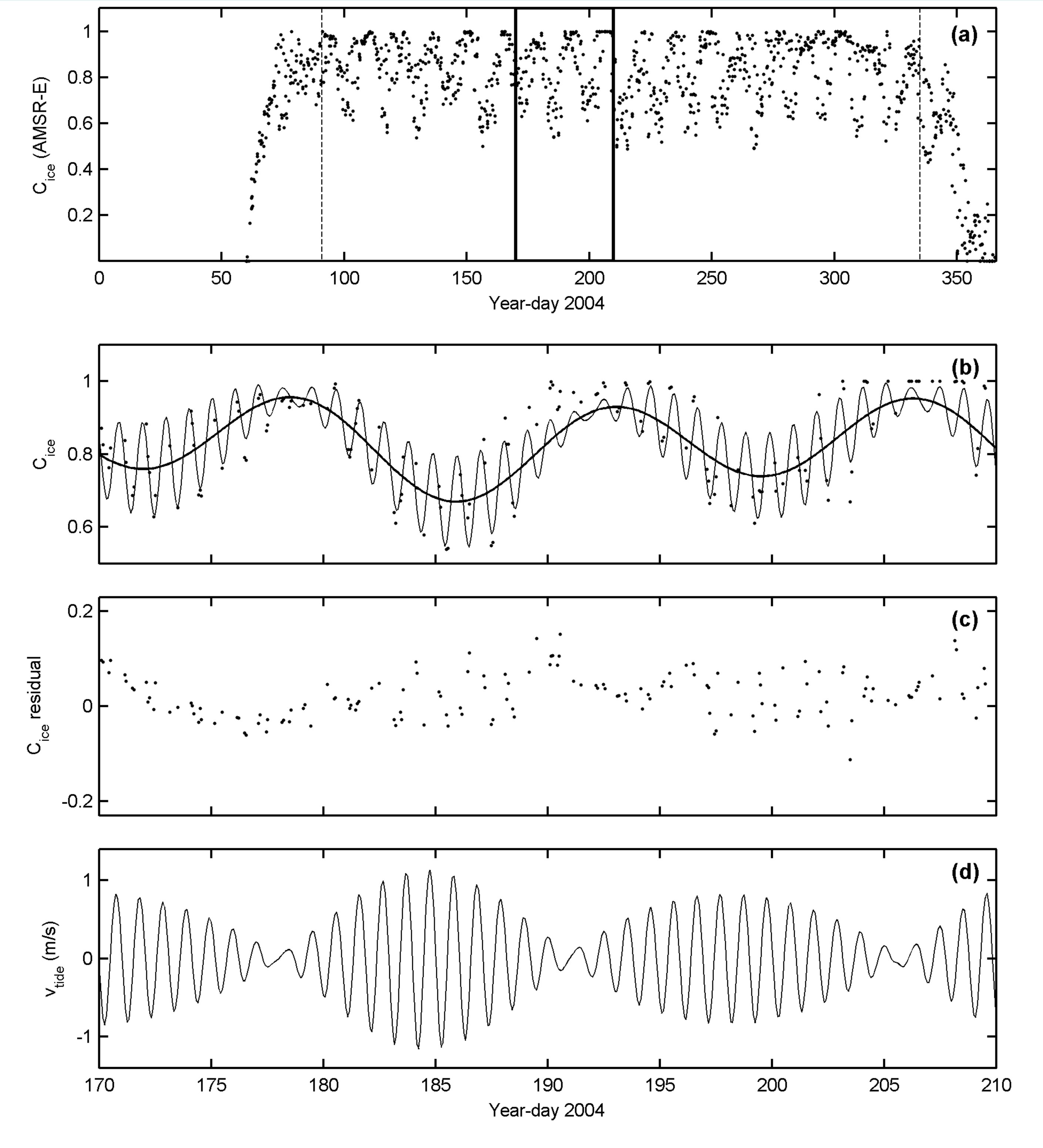

Figure 4*. *a) Original AMSR-E Cice data, b) Cice with tidal and spring neap cycle fit, c) Residuals from tidal fit, d) Cross-slope velocity from tide prediction model.*

Results

For the 25x25 km area, coefficients O1 and K1 have a significant effect on C_{ice} (Fig. 4, Table 1). We applied the method to the rest of the Ross Sea to generate a map of tidal effects on sea ice (Fig. 5). Expected values of tidal coefficients, *A*, can be calculated from local tidal divergence generated by a tidal prediction model:

$A = \sigma(\mathrm{Div}_h \times \mathbf{u}_{ocean})T_{tide}/2^{1/2}\pi$,

where T_{tide} is the period of the constituent, assuming free drift of sea ice.

Differences between amplitudes (compare Fig. 5 middle and bottom) illustrate where the free drift of sea ice assumption fails and the ice may respond by ridging and rafting instead.

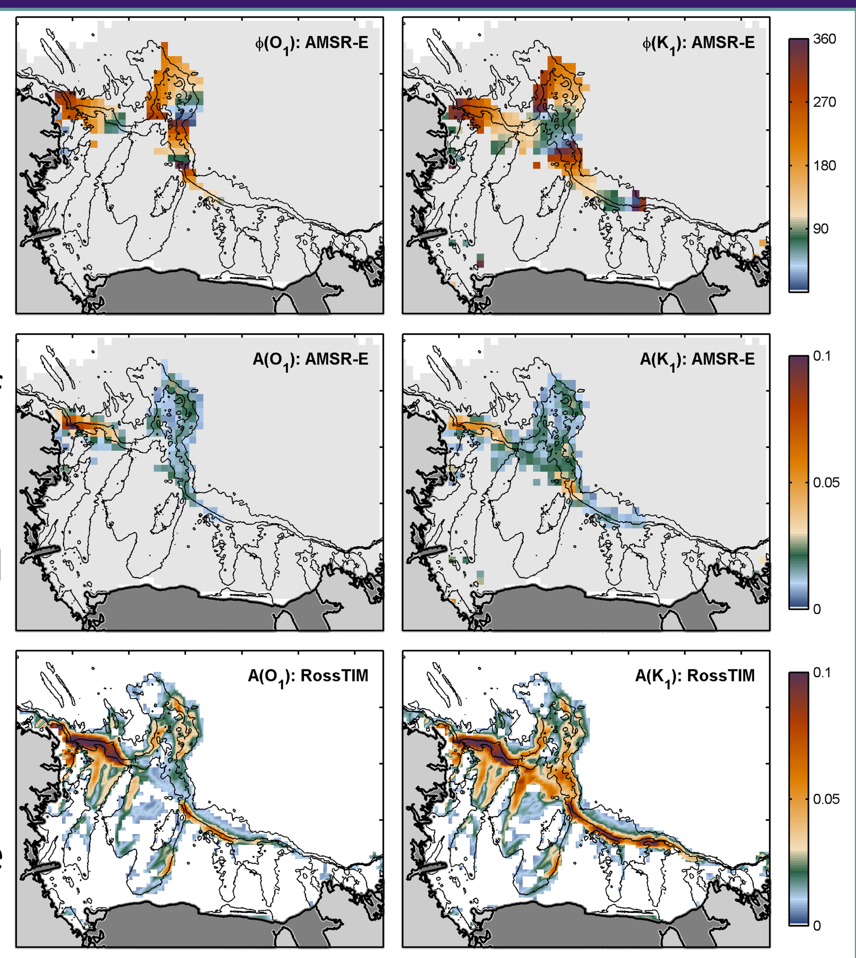

Figure 5*. *Left: O1, Right: K1. Top, middle: Phases, amplitudes from AMSR-E swaths. Bottom: Amplitude coefficients (A) calculated from tide prediction model.*

Constituent	Period (h)	Cross-slope current (cm/s)	C_{ice} AMSR-E	C_{ice} ROMS	H_{ice} ROMS (m)	Shflux ROMS (Watt/m^2)
Long-period						
MF	327.86	0.02	0.096	Not resolved in model		
Diurnal						
O1	25.82	48.7	0.070	0.113	Not Sig	62.34
K1	23.96	30.6	0.046	0.061	Not Sig	33.31
P1	24.00	9.9	0.006	Not Sig	Not Sig	Not Sig
Ratio						
O1:K1		1.59	1.52	1.85	-	1.87

Table 1. *Comparison of tidal coefficients in AMSR-E data and model data.*

Synthetic Tides

In order to test the validity of our results, we created a synthetic tidal signal of two sine waves with periods of O1 and K1. This signal was sampled at satellite pass times and processed with our analysis method. The same two frequencies were returned without any spurious signals, but with amplitudes diminished by 30%.

Likewise, we created a second synthetic signal as a single sine wave with period = 24.7h. It was sampled at satellite pass times, and then a daily average was calculated. In the daily averages, there was a false signal at 27 days with amplitude 60% of the original diurnal signal.

Regional Ocean Model

A ROMS 5-km model of the Ross Sea, including ice shelves, dynamic sea ice, and tidal forcing was used to evaluate the effect of tides on C_{ice}, ice thickness, and surface heat flux. Here, C_{ice} results (Fig 6.) are compared with satellite data in Table 1, and differences in the same model run with and without tidal forcing are shown in Figs. 6, 7, 8.

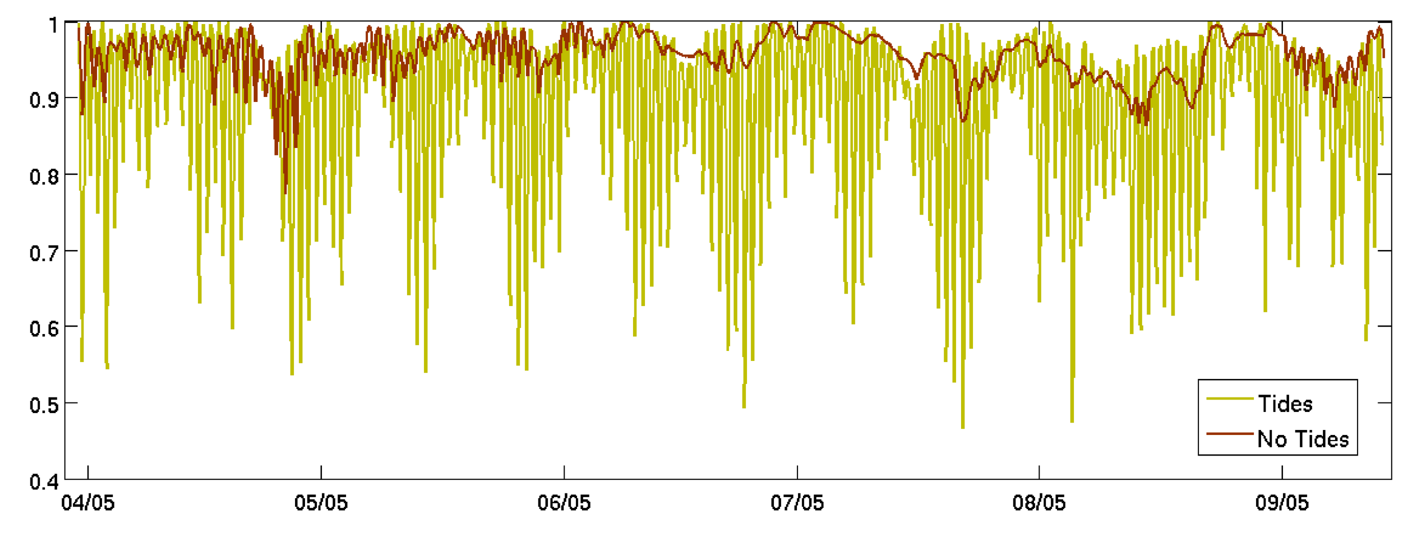

Figure 6. *Cice for ROMS model, for cases with and without tides.*

**From:* Mack, S., L. Padman, and J. Klinck (2013), Extracting tidal variability of sea ice concentration from AMSR-E passive microwave single-swath data: A case study of the Ross Sea, *Geophys. Res. Lett.*, 40, 1-6.

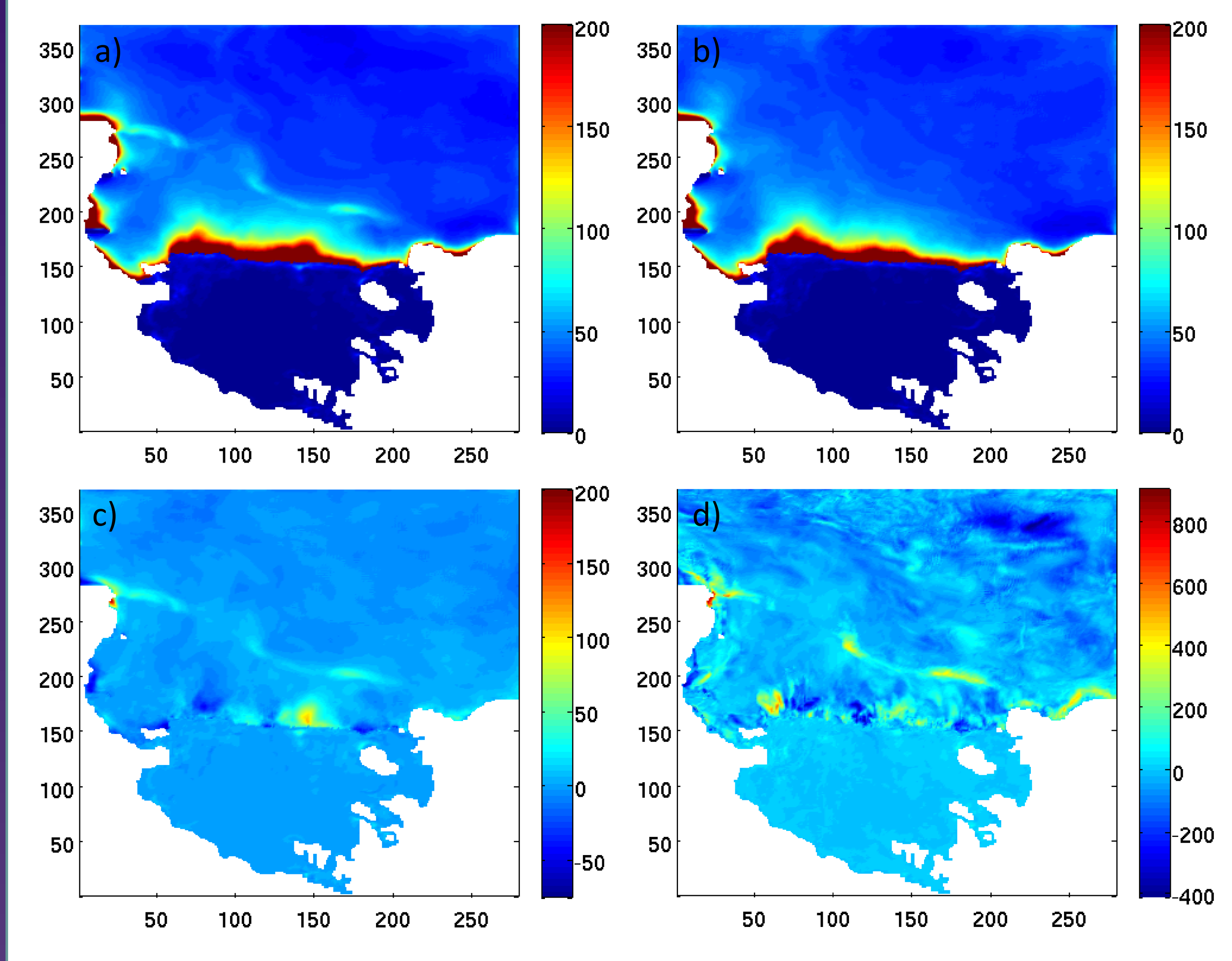

Figure 7. *a) Mean surface heat flux, Mar-Sept, tides; b) Same as a), no tides; c) Mean heat flux difference; d) Maximum heat flux difference. (tides - no tides, Watts/m^2)*

Tidal effects in model

We find that modeling tidal effects of C_{ice} closely follows satellite observations. Investigating other parameters, we find the thickness of the ice floe does not seem to vary significantly on a tidal time scale, but the surface heat flux does. Figure 7 shows the magnitude of surface heat flux changes—up to 100 Watt/m^2 on average over the winter season in tidally active regions along the shelf break.

Figure 8 shows that large tidally induced excursions in surface heat flux can drop the surface temperature enough to begin ice production in the Northwest corner. This may be related to local wind forcing and air temperature, and needs further investigation.

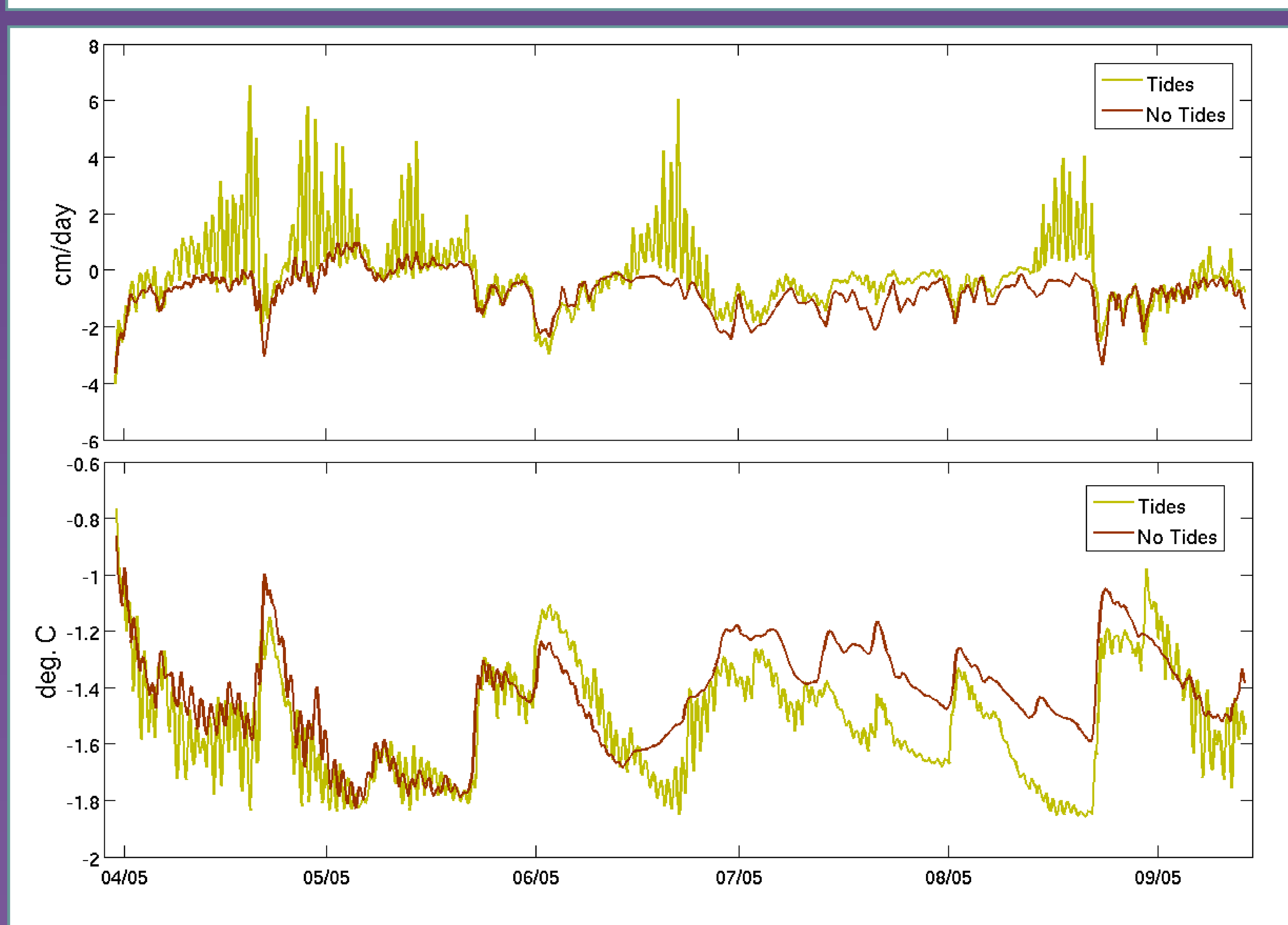

Figure 8. *Top: Ice-ocean mass flux; Bottom: Surface Temperature; over a 25x25km box in the Northwest corner.*

Conclusion

We demonstrate a new method to extract diurnal tidal variability in sea ice concentration from AMSR-E swath data in the Ross Sea. This new data confirms results from a regional ocean model with tidal forcing. The model illustrates the effects tides can have on ice concentration, surface heat flux, and other processes. Further investigation is needed to understand the extent of tidal effects in the Ross Sea.

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Computer Usage: Center for Coastal Physical Oceanography

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